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ABSTRACT

The purpose of this module is to develop a general procedure to decide the feasibility of land application as a waste management alternative, given a specific problem situation. This information provides a framework within which to apply the information presented in all other modules in the program. An outline of the general procedure followed in engineering design is presented, then related to the procedure to be followed for land application. The design procedure is divided into a two-level approach. The first level is intended to roughly approximate the initial feasibility determination for this technology. Major problems created by water management, solids and organic characteristics of the wastes, nutrients, toxic elements, and site determination are identified. This analysis is illustrated by the design example of land application of harbor dredge spoil. Level II analysis makes use of the comprehensive modules to examine the limiting factors in detail and other major concerns which will affect the final problem solution. (Author/BE)

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Land Application of Wastes

An Educational Program

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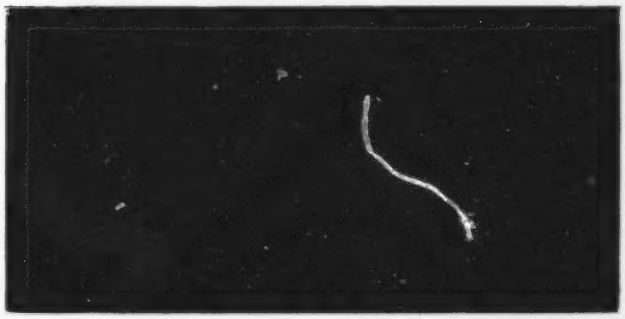

CORNELL UNIVERSITY
New York State College of
Agriculture and Life Sciences
A Statutory College of the State University
Ithaca, New York

SE 025 020

LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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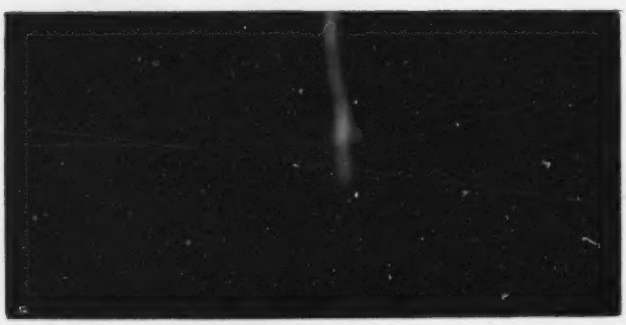

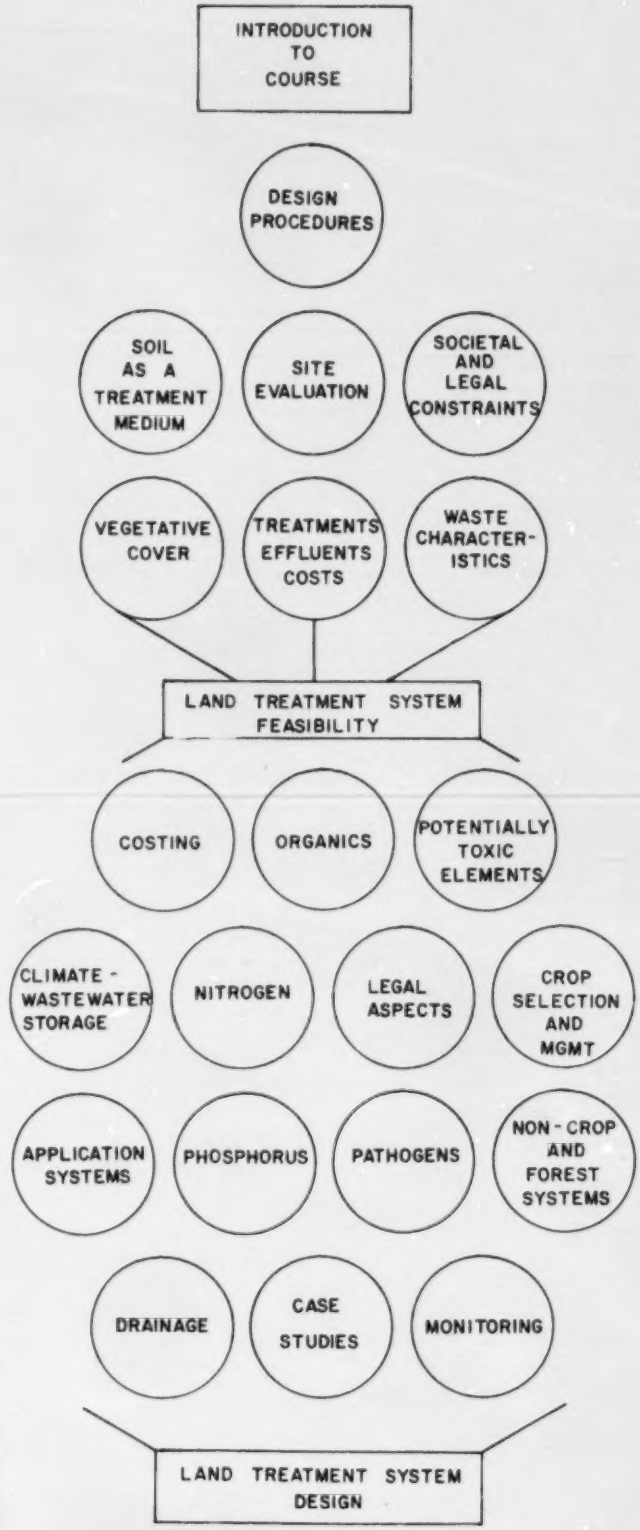

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DESIGN PROCEDURES
FOR LAND APPLICATION OF WASTES
Module 6
January, 1978

Summary

The purpose of this module is to develop a general procedure to decide the feasibility of land application as a waste management alternative, given a specific problem situation. This information provides a framework within which to apply the information presented in all other modules in this program. Emphasis is placed on the Level I analysis, the intent of which is to present the subject matter and analytical techniques required for feasibility decision making. This module's primary function is to serve as a brief introduction, or guide, to the design problems addressed by participants in workshops or courses in which this educational program is used. The same function may be served for designers facing similar problems in actual practice.

An outline of the general procedure followed in engineering design is presented, then related to the procedure to be followed in this program for land application. By applying the material in these modules, it is possible to carry out the initial and detailed feasibility determinations of land treatment options. This results in the recommendation of one option for detailed design and implementation.

The design procedure is divided into a two level approach. The first, Level I, is intended to roughly approximate the initial feasibility determination for this technology. Major problems created by water manatement, solids and organic characteristics of the wastes, nutrients, toxic elements, and site determination are identified. This analysis indicates the factors which dictate the solution requirements, i.e., the limiting factors. This Level I analysis is illustrated in this module by the design example on land application of harbor dredge spoil.

Level II analysis makes use of the comprehensive modules to examine the limiting factors in detail and other major concerns which will affect the final problem solution. Modifications which would significantly change the solution feasibility are identified at this point. Site evaluation, from Level I, is examined in further detail for the specific sites which are determined as feasible.

The overall outcome of this two level analysis would be the ability to determine whether land application of wastes is technically feasible, to estimate whether it would be economically competitive with other major alternatives, and to identify specific locations for implementation of solutions. This procedure could form the basis for detailed planning, engineering and on-site investigations.

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Objectives

Upon completion of this module, the participant should be able to:

1. Define Level I and Level II design procedures and demonstrate an understanding of how these steps relate to an overall engineering design sequence.

2. Make use of the other Level I modules in this program to identify potential limiting factors for land application systems, and estimate land area requirements for each factor.

3. Demonstrate the use of mapping techniques in site evaluation for land application systems.

4. Identify other considerations, not included in the design example in this module, which would also be part of Level I and II feasibility analyses for land application projects.

Introduction

When the alternative of placing sludge or wastewaters on land is considered, many questions arise as to the impact of specific factors. Water movement and runoff, pathogen control, nutrient utilization and many other considerations will influence the final design. Complex engineering problems are usually solved using a rational procedure which allocates priorities to the variables, with the most limiting parameter dictating the final solution. To date, no general design procedure is in use or available which will assist in evaluating the major variables that influence the design of a land application system. The information in this module is intended to illustrate a screening procedure combining the information in other modules which will lead to feasibility determinations and site specific solutions for the land application of wastes.

The goal of this module is to develop a general procedure, based on an understanding of the pollutant management capabilities of soils, for evaluating the feasibility of land application of waste under various conditions. This procedure is a rational screening method which should lead to 1) the identification of specific limiting factors, 2) an idea of the safety factors involved in using land application of waste for non-limiting pollutants, and 3) site locations that combine the required characteristics for safe pollutant management. Essentially the information in this module provides a framework for the utilization of the information presented in all other modules in this program.

Design Procedure

General Engineering Design Procedures

Because of the wide scope of knowledge needed in planning solutions for land application of wastes, many individuals involved with these designs may not be engineers. The rational problem-solving approach common to much engineering practice may be alien to some members of the design team. Therefore, before proceeding directly to land application requirements, it is useful to consider the general design approach.

This design approach may be represented as in Figure 1, having six distinct steps (A-F) ranging from problem definition through evaluation of the implemented solution. After the problem has been defined with the assistance of affected interest groups, the possible solutions are listed. Initial feasibility of the suggested solutions should lead to several distinct alternatives. These are then further defined, with some being eliminated. These two steps essentially represent the type of activities carried on at Level I in this program. All information needed to complete the Level I design function for land application of wastes is included in the seven introductory modules (Modules 1-7) of this program.

The general engineering design procedure is presented as a six-step process ranging from problem definition through feasibility studies, detailed solution, implementation, and evaluation.

The next step is to identify, in depth, the major limitations of the design possibilities and to identify any factors which might prohibit implementation of viable solutions. Generally, one solution will be favored or several will appear equally worthy of further consideration based on the Level I analysis. The favored solution(s) is analyzed to see if it is technically adequate to achieve the design objectives and compared with other likely solutions for technical and cost-effectiveness. The designer at this stage includes as many factors as possible for consideration. Based on this analysis, one solution is recommended for final design and implementation. These

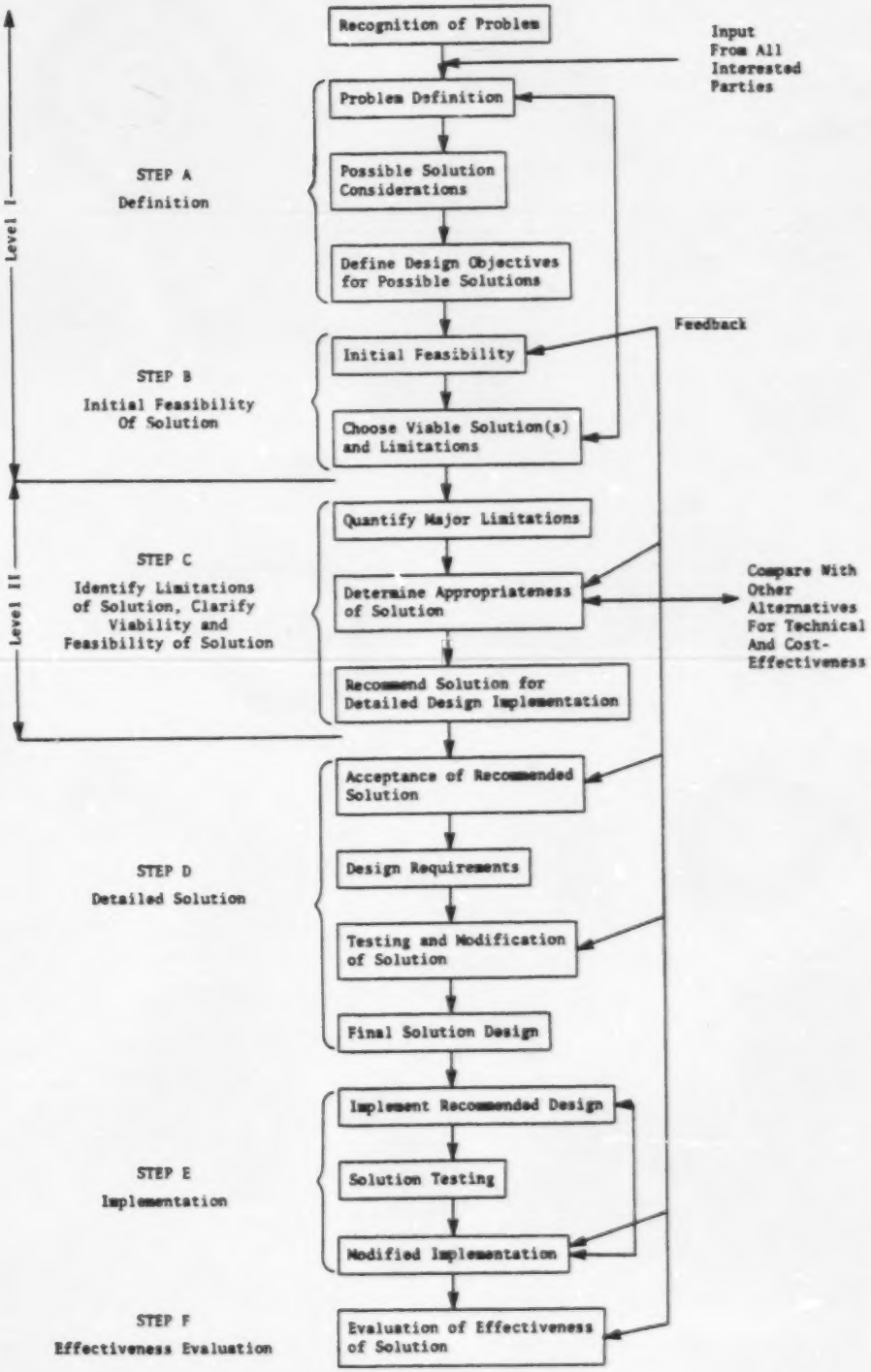

Figure 1. Illustration of the general steps involved in an engineering design procedure.

procedures make up Level II design in the Land Application of Wastes Program, and any further steps outlined in Figure 1 are outside the scope of this program.

Following selection and acceptance of a solution, the detailed solution is then defined and design work is carried out. Any pilot plant analyses or field investigations would occur at this stage (Step D). The solution is then implemented (Step E). Under ideal conditions the implemented solution would be evaluated and its effectiveness in solving the original problem examined. This would lead to feedback which would be valuable in improving engineering practice. Unfortunately, this last step is often omitted in planning and design, however, reports are published on the performance of various engineered systems which designers attempt to adapt to their particular problems.

Relation of this Program to General Engineering Design Procedure

Obviously, this educational program cannot provide all the skills and knowledge needed to take a participant from a minimal background in land application of wastes through all six design phases shown in Figure 1. The information contained in all modules of this program should assist the participant in developing solutions through the stage designated as Step C in Figure 1. The Level I design procedure includes problem definition and initial solution definition and limitations, Steps A and B. The Level II procedure permits a more in-depth evaluation of this alternative (Step C).

Modules in this program can be used to perform initial and detailed feasibility analyses of land application vs. conventional alternatives. These functions are referred to as Level I and II analyses.

The three important pieces of information which participants should be able to develop upon completion of this design procedure are:

- determine whether land application of sewage sludges, industrial sludges and wastewaters represents a viable alternative to conventional discharge systems;

- identify area-specific information that would enable one to estimate the type of land application technology that is most feasible for specific geographical locations;
- estimate the cost effectiveness of the most viable alternatives.

It is the goal of this program to enable the participants to be able to make feasibility decisions with only several hours of study after the problem has been defined, and to provide estimates of types of systems, potential site locations and cost-effectiveness of land application of wastes after additional investigation.

Design Procedure for Land Application of Wastes

Seldom have those involved with the development of waste management systems had to deal with as many variables as the land application of wastes. These systems require integration of physical, chemical, and biological pollutant control phenomena with climate, crop production, and uncontrollable natural phenomena. In order to make this educational program easier to assimilate, it has been divided into two phases - Level I and Level II as discussed above. In order to complete Level I design, participants should be familiar with the information presented in the first seven modules of the program. Only the most prominent considerations are included at this level, and detailed descriptions are kept to a minimum.

There are two general temptations for the program participants at this point. Some may become frustrated with the lack of detailed definitions and descriptions. However, the information in the Level I modules should be viewed as being analogous to seeing only the "tip of the iceberg". A considerable amount of supporting material is provided in subsequent modules.

The second temptation is that the initial information will be adopted as inflexible "rules of thumb". It

Level I design makes use of the basic principles in Modules 1-7. Information in these modules should neither be considered complete in detail or as "rules of thumb" which may not be modified.

should be kept in mind that the initial feasibility determination procedure (Level I) is presented to obtain data rapidly for initial decisions. The decisions and limitations defined at this point should be considered temporary until further supporting data is developed. This procedure may be considered analogous to advice given by a consultant on initial contact by a client. Although the Level I procedure is sound and should fulfill the needs of an initial feasibility determination, more in-depth analysis is required in order to proceed with a final design.

The general Level I design procedure is illustrated in Figure 2. The waste problem is defined by a characterization study which should identfiy any factors which would prohibit land application of wastes. Modification of the problem by waste treatment at the source may be required for technical, legal, or social reasons. This source treatment may not be technologically- or cost-effective. Other circumstances might prohibit land application, such as the unavailability of land. At this point, only enough analysis should be conducted in regards to site evaluation to know that significant land area is available with the required soil properties within a certain radius. The land area to safely neutralize the various classes of pollutants would then lead to specific requirements and systems which could be costly. Data at Level I could be used to make initial feasibility decisions as to whether land application of wastes represents a viable management alternative.

The outcome of initial feasibility study (Level I design) is whether land application is a viable alternative requiring further analysis.

After the decision is made to pursue land application further, Level II analyses begin. This level is characterized by a greater depth of analysis of pollutant-soil interactions, and considerably more attention to potential site location and evaluation. A summary of the major steps involved with this second level of analysis in presented in Figure 3. The major topics to

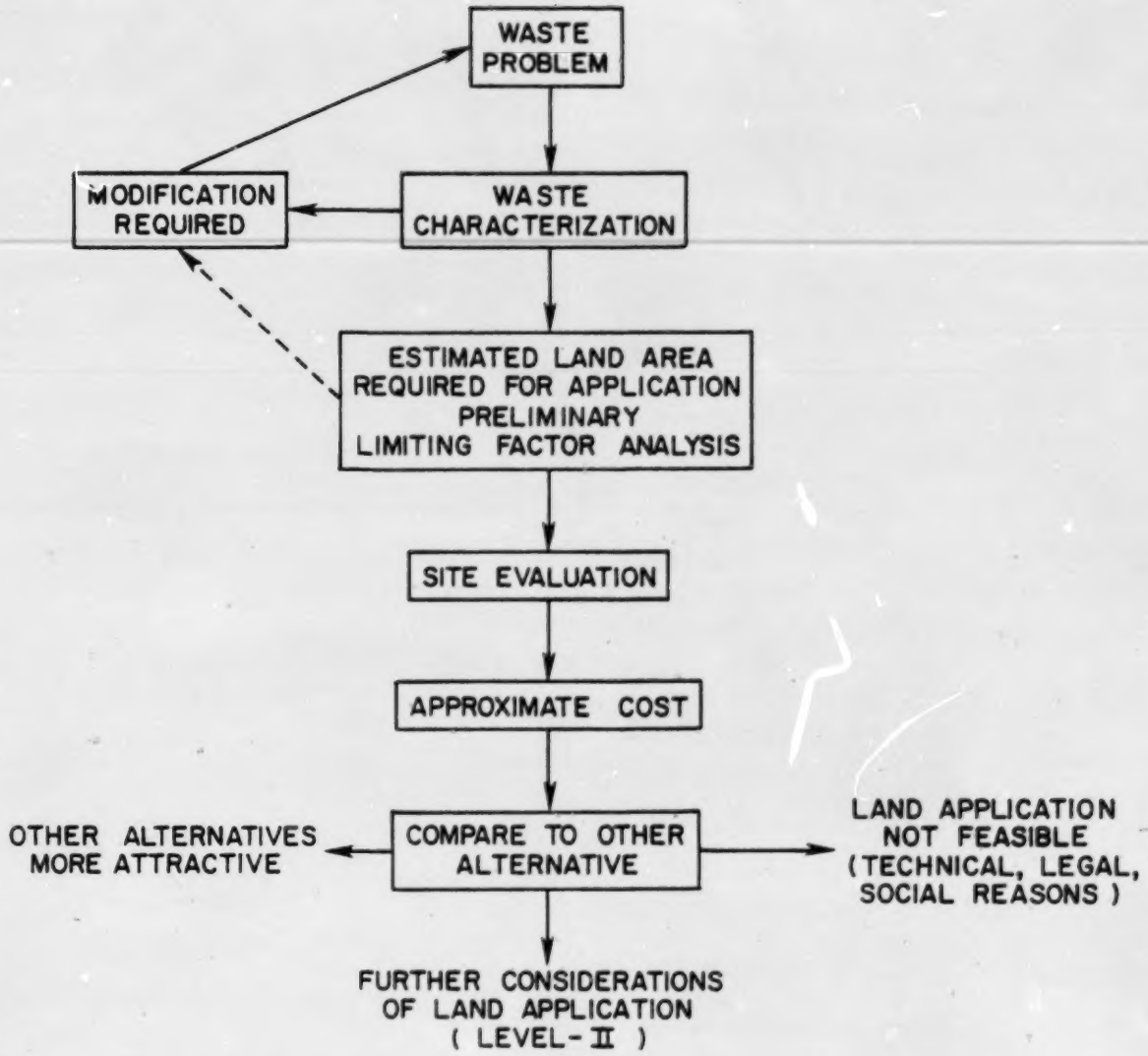
WASTE PROBLEM
MODIFICATION REQUIRED
WASTE CHARACTERIZATION
ESTIMATED LAND AREA REQUIRED FOR APPLICATION PRELIMINARY LIMITING FACTOR ANALYSIS
SITE EVALUATION
APPROXIMATE COST
OTHER ALTERNATIVES MORE ATTRACTIVE
COMPARE TO OTHER ALTERNATIVE
LAND APPLICATION NOT FEASIBLE (TECHNICAL, LEGAL, SOCIAL REASONS)
FURTHER CONSIDERATIONS OF LAND APPLICATION (LEVEL-II)

Figure 2. Simplified Level I design procedure for land application of wastes.

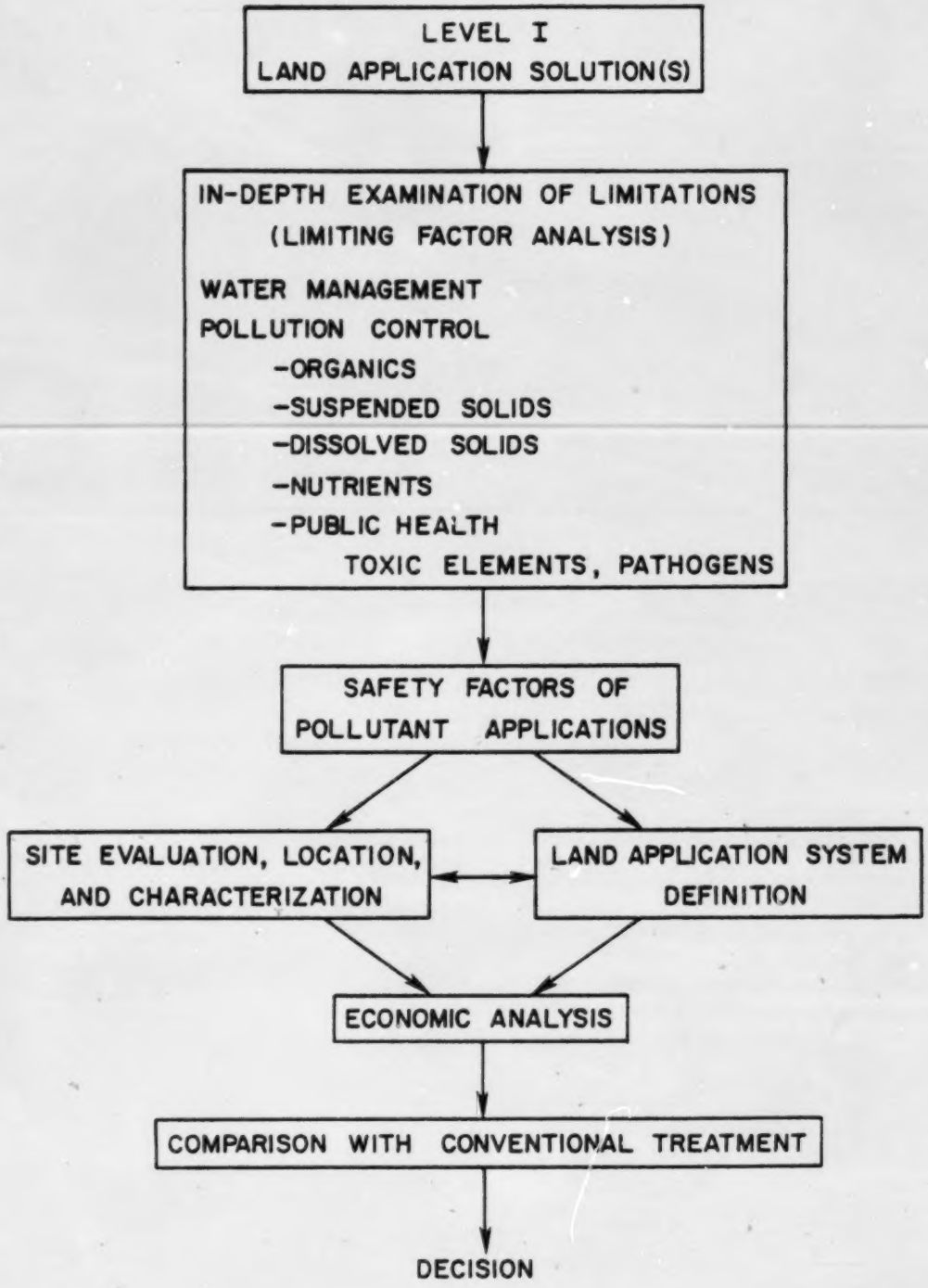

Figure 3. Generalized activities completed during Level II analysis.

be considered are: the limiting factors and determination of alternatives which would have the capability of eliminating particular inhibiting variables. For example, pathogen movement may be considered to be a limiting hazard, from the public health viewpoint. Obvious alternatives would include disinfection of the waste prior to application, or modification of the application site or method.

In Level II design, potential limiting factors are examined in detail. The limiting factor determines land area requirements for a particular land treatment option. Specific site selection can then be made.

Usually, one waste parameter will determine the largest land area required for safe application of the wastes. This is then identified as the limiting factor in the solution. This indicates that for all other parameters, the waste could be applied at a higher rate, or to a smaller area. Comparison of the land area required for safe application of each of the other pollutants to that required for the limiting factor is indicative of the safety margin involved in the application of that waste parameter. This will be illustrated in the example included in this module.

The next major consideration is whether sufficient land area is available to implement the solution. Finally, site location, land area requirements and application system definition enable a detailed cost estimate to be prepared. Then, after comparison with other technically feasible alternatives, the decision is made as to what system will be recommended for the waste treatment problem under consideration.

Outcome of Level II design is recommendation of a specific alternative to implement.

Major Design Considerations

Topic Interactions - Level I and II Designs

The specific interactions of various parameters with waste application to land at Level I are summarized in Figure 4. This illustration represents factors that are useful in identifying the critical parameters as well as the limiting factor in the design. The participant

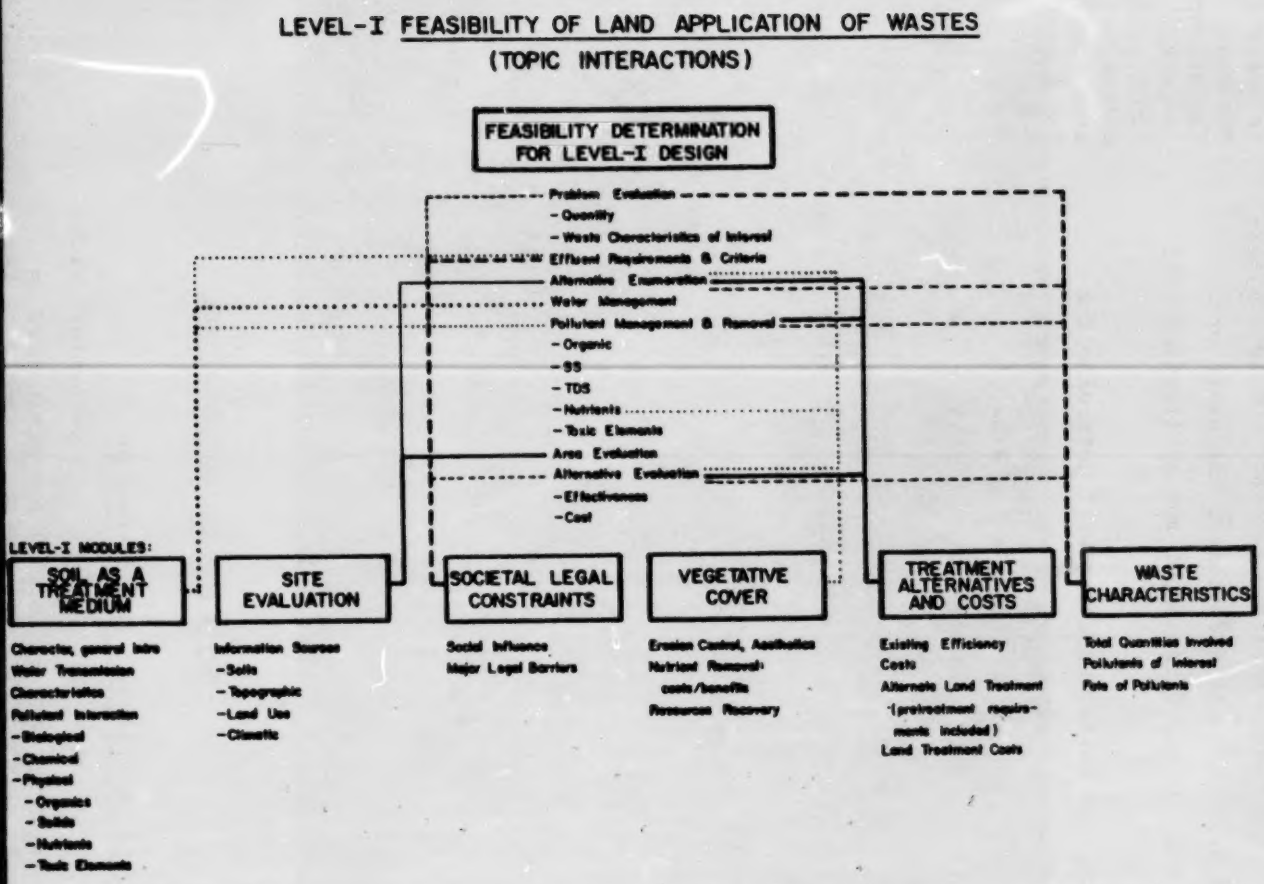

Figure 4. Interaction of introductory modules for Level I design procedure.

should be able to use the other six Level I modules to examine potential land application sites and to identify safe application rates of pollutants, following the general procedure outlined in this module. After completing the program modules the participant should be able to describe the major background reasons for the pollutant loading limitations.

Preliminary Site Evaluation

General Approach - The determination and choice of suitable waste treatment sites is one of the most difficult tasks in producing a workable system. The problem definition must be integrated with a wide range of variables such as: soil types and characteristics, topography, groundwater location and movement, crop production capability, and present and projected land use. Although it is difficult to combine all of these variables, a relatively simple procedure can be developed which is capable of identifying sites which combine the necessary properties. This method relies on the availability of detailed maps of potential application areas. Fortunately, the U.S. Geological Survey and the Soil Conservation Service provide a large amount of detailed information for most parts of the U.S. Details on sources of data are given in Module 2, "Site Evaluation". Some states, such as New York, have also developed maps showing the distribution of farmland, idle cropland, forests, and other land uses.

Site selection is simplified by overlaying topographic, soil survey, and land use maps to identify areas having favorable features for land application.

Three types of maps are helpful for site location and evaluation: soil survey maps, topographic maps classifying areas according to the characteristics of the terrain, and land use maps. These maps, when superimposed on each other, clearly illustrate areas where common features occur. The desirable area can then be estimated and compared to the acreage required for safe application of the limiting factor in the waste. This simplified analysis is illustrated in the following example (see Figures 6, 7, and 8 and the accompanying discussion).

Design Procedure Example - Feasibility of Land Application of Polluted Dredged Harbor Sediment

Problem Definition - It would be more common to use municipal wastewater or sludge to illustrate the principles involved with the design of land application systems. However, to emphasize the general applicability of this procedure to complex materials, the rather unusual problem of land application of dredged harbor sediments will be used. The chosen example in this module represents actual locations and situations. All problem descriptions have been changed in some way to avoid the presentation of actual data not available to the public. This will not affect the value of the example in illustrating the limitations of this technology.

A design example of land application feasibility for dredged harbor sediments is used to illustrate the general applicability of the procedure.

To maintain the nation's navigable waterways, the U.S. Army Corps of Engineers each year dredges 300 million yd^3 of channel materials (Anon., 1975). This is more than 100 times the total quantity of sewage sludge generated in the United States (Dean, 1973; Fuhrman, 1973). These dredged materials often contain large quantities of toxic materials and large amounts of water. Economic disposal, without adverse environmental impact, is a major problem. Past practice has included transport of the material to open deep waters. However, increasingly strict environmental legislation has limited this option, and has resulted in the increased use of the other common alternative - storage in diked lagoons. This practice consumes 7000 acres of new land every year.

The total cost of management of the dredging problem in the U.S. is about $170 million annually. Because of the increasing concern for protection of littoral areas and the rising costs of land, diked storage of sediment is also being reviewed as to its long term viability as a solution to dredged material disposal.

Much of the dredged sediment is composed of valuable top soil washed from nearby agricultural land. Thus one obvious solution for deposition of the dredged material would be to use agricultural land as a disposal site. This solution has been rarely used for two reasons:
a) it is usually costly to transport the sediment, and
b) anticipation of problems resulting from the application of sediment on the soil systems.

The problem is to define the feasibility of placing the dredged material on agricultural land. No consideration will be given to the economic feasibility of this alternative in this example.

General Waste Characteristics and Objectives of the Example

The U.S. Army Corps of Engineers, Buffalo, New York branch estimates that the harbor at Olcott, New York must have 30,000 m^3 of sediment removed. An aerial view of the community and marina leading into Lake Ontario is shown in Figure 5. A number of samples of this sediment indicate that it is highly contaminated with grease and oil and has up to 1000 ppm of zinc and lead. One of the disposal alternatives for this sediment is to place it on land used in productive agriculture. Since the dredged material contains high concentrations of potentially toxic materials, many questions arise as to the desirability of using this alternative. The specific objectives are to:

1. Quantify the major pollutants and their safe application rates.
2. Relate the pollutant application rate to the required land area.
3. Review the land use practices to determine the availability of agricultural land in the area.
4. Determine the portion of the agricultural land which has characteristics which will promote the control of pollutants.

Figure 5. Aerial view of Olcott, New York.

This example will not present any economic and technical comparison of land application with other treatment options. This is a necessary part of any feasibility analysis, however, and would be carried out in an actual problem situation.

One of the first considerations with this waste is defining the constituents which must be evaluated with respect to application rates. In general, it would appear that the regulations being developed to control the application of materials such as sewage sludge are highly restrictive.

The Environmental Protection Agency is presently cooperating with the U.S. Department of Agriculture (USDA) and the Food and Drug Administration (FDA) to determine the precise levels of various contaminants that can be placed on land used for food production. In the interim, the USDA has developed the guidelines shown in Table 1 for the application of certain potentially toxic materials on agronomic soil. These guidelines appear, along with means of approximating loadings of other waste constituents for Level I design in Module 3, "Soil as a Treatment Medium". Additional data and other approaches limiting the application of waste sludges are given in Module 11, "Potentially Toxic Elements".

Guidelines for potentially toxic element application must be used since the dredged spoil is reportedly high in some heavy metals.

Table 1. Maximum sludge metal additions to privately owned farmland.

Metal Addition (kg/ha) to Soils with a Cation Exchange Capacity (meq/100g) of:			
Metal	Less than 5	5-15	Greater than 15
Pb	500	1000	2000
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

Dowdy, et al. (1976); Jorling (1977); EPA (1977)

With reference to the contaminant levels and disposal standards given in Table 2, it is clear that the "open lake" dumping policy would not be applicable since the concentrations of many pollutants are higher than the maximum values which have been suggested by EPA. There is little question that on first consideration of placing this material on land one would not be optimistic about the possibilities.

Pollutant Soil Application Limitations - As the second step in the Level I analysis the factors which may limit agricultural land disposal of sludges and the risk involved with this practice will be estimated. This will be accomplished by following the pathways shown in Figure 4. It should be emphasized that little data is available on the effects of dredged materials on food crop production. If it is assumed that the sediment is uniform, total quantities of constituents can be calculated from the values shown in Table 2. Totals are displayed in Table 3. Now that the total quantities of pollutants are estimated, the screening procedure to identify the limiting design parameter can be initiated.

Toxic Elements - The most common concern with land application of sludges is the question of the effect of potentially toxic elements on the soil-crop system. This topic demands a conservative approach because of the problems that could ensue. In most soils, the metals are rapidly immobilized and accumulate in the first several centimeters of soil. Even where heavy metals accumulate, many plant systems and the human body have the inherent ability to avoid accumulation of the toxic elements. However, there are unknown areas and dangerous exceptions that must be considered.

Given the total quantity of lead and zinc to be applied, from Table 3, and a typical agronomic soil CEC in the 5-15 meq/100g range, land area requirements can

Table 2. Composition of Olcott, New York harbor sediments as measured April 12, 1972. All values on dry weight basis.

Parameter	Sample Number * 1	2	3	4	5	6	EPA Criteria Open Lake Disposal
Volatile Solids, %	11.3	14.6	10.0	1.2	2.3	0.5	6
COD, %	14.0	18.6	12.5	0.5	17.3	0.5	5
Oils and Grease, mg/kg	6100	9960	4220	230	490	180	1500
TKN, mg/kg	3190	4670	3220	--	485	1500	1000
Lead, mg/kg	580	770	320	68	96	20	50
Zinc, mg/kg	260	305	240	120	120	66	50
Hg, mg/kg	1.47	0.92	3.45	0.23	0.91	0.88	1
Phosphorus, mg/kg	4000	4100	3300	1100	2900	400	--

* Sample stations numbered from the bridge (No. 1) to the open lake.

Table 3. Estimation of total quantities of materials in 30,000 m^3 of Olcott Harbor sediment using linear average of all values shown in Table 2.

Material	In-Place Sediment Concentration, Average of Six Samples	Estimated Total Quantity For Disposal
Volatile Solids	6.66%	3.2×10^6 kg (7.06×10^6 lbs)
COD	10.6%	5.1×10^6 kg (11.3×10^6 lbs)
Total Kjeldahl Nitrogen	2610 mg/kg	1.26×10^5 kg (2.76×10^5 lbs)
Oils and Grease	3520 mg/kg	1.7×10^5 kg (3.74×10^5 lbs)
Lead	308 mg/kg	1.48×10^4 kg (3.26×10^4 lbs)
Zinc	185 mg/kg	0.89×10^4 kg (1.96×10^4 lbs)
Hg	1.31 mg/kg	63 kg (140 lbs)

be computed using the maximum additions of Zn and Pb from Table 1.

The computation for lead:

$$\frac{1.48 \times 10^4 \text{ kg applied}}{1.00 \times 10^3 \text{ kg/ha}} = 14.8 \text{ ha required}$$

and for zinc:

$$\frac{0.89 \times 10^4 \text{ kg applied}}{0.50 \times 10^3 \text{ kg/ha}} = 17.8 \text{ ha required}$$

Land area computations are made for Zn and Pb based on guidelines presented in Table 1.

The levels of Cu, Ni, and Cd should also be ascertained by laboratory analysis of the sediment, and required land areas computed in the same manner. Since Zn is limiting of the two elements for which figures are available, land area will be estimated on that basis. 17.8 ha, approximately 43 acres, are required for Zn. Assuming that the concentrations of Cu, Ni, and Cd are not limiting compared with lead and Zn, adequate area for sediment application would be 50 acres.

Greases and Oils - For a specific problem such as grease and oil, it may be necessary to turn to the research literature. Large quantities of petroleum products are lost to the environment. For this reason, a considerable amount of information is available on the fate of grease and oil in the environment. In general, the soil environment appears to be able to accept large quantities of petroleum products, since most oils and grease are eventually decomposed by microbial activity. Further, it would appear that the hydrophobic characteristics would contain these organics in the surface of the soil so that contamination of the groundwater would be a minimal problem.

On the basis of greenhouse pot experiments (Schwendinger, 1968), beans were most easily damaged by crude oil, ryegrass somewhat less, and sorghums continued to grow in soil heavily polluted with oil. For biodegradeable cooking oils, it was found that application rates as high as 112 metric tons per hectare resulted

in oil decomposition rates of 8 tons/ha/week with no evidence of toxicity to the decomposition systems in the soils (Smith, 1974). The rule of thumb that has been developed is: one kilogram of oil per square meter of soil surface is considered to be the point at which damage to plant life begins (Schwendinger, 1968; Ellis and Adams, 1961). Using this as the application rate for Olcott sediment, the safe application for grease and oil application would require a land area of 1.7×10^5 square meters or 42 acres, or a land area slightly less than that needed for safe application of potentially toxic metals.

Grease and oil application is based on values reported in the literature from experience with other wastes.

Organic Solids Application Rates - The organic assimilation capacity of soils is highly variable depending on the detailed soil characteristics (see Module 17, "Organic Matter"). In general, soils are composed of 3 to 5 percent organic matter by dry weight. Thus in the top two feet of soil, there will be more than 20×10^4 lbs/acre of organic matter. Excepting for the oil and grease, it is likely that the organic matter in the sediments will be resistant to decomposition. In this form it may use little oxygen and application of large quantities may have little detrimental effect on the soil. Although few guidelines are available, it is likely that the addition of a total amount of organics equal to 10 percent of the existing soil organics would have little effect and even doubling the organic content in the upper two feet should not cause long term detrimental effects. If this analysis holds true, the safe application area would be less than about 350 acres and could be as small as 35 acres.

Organic solids application is related to the amount of organic matter likely to be present in the native soil.

Nitrogen and Phosphorus Control - The nitrogen and phosphorus in the sediment are likely to be in the organic form. As the material enters into the decomposition cycle in the soils these nutrients will be mineralized. Phosphorus will not be a potential problem

because large quantities are rapidly immobilized in most soils. However, conversion of organic nitrogen to ammonia and then to the oxidized forms may result in nitrate contamination of the groundwater. Thus nitrogen will be considered as a nutrient which must be applied at a controlled rate.

The control of nitrogen in the organic form should be viewed in relation to the background concentration in the soil. The quantity of organic nitrogen in soils varies from 0.1 percent of the dry weight to 2.5 percent, depending on the character of the soil (see "Nitrogen Considerations", Module 15, for further information). The total quantity of organic nitrogen in the plow layer of soils may vary from less than 2500 lbs per acre to more than ten times this value. Net mineralization of this soil nitrogen occurs at a rate of about 1.2 percent per year (Bouldin and Lathwell, 1968). In other words, as much as several hundred pounds of nitrogen could be mineralized per acre over a few years. In most cases, the total quantity of nitrates that reach the groundwater from mineralization is minimized due to one of the following:

- low net available nitrogen as a result of a high C/N ratio,
- denitrification of the nitrified nitrogen forms,
- removal in the crop cover.

Organic nitrogen addition is related to the quantity present in soil, net mineralization rates, and normal fertilizer additions.

Fertilizer applications commonly add 50-150 lb/ac-yr of nitrogen in the available forms of ammonia or nitrates for crop production. If it is assumed that the organic nitrogen in the dredged material gives up its nitrogen at the rate of 10 percent per year and that no other source of nitrogen is utilized, the amount of cropland, given that 100 pounds of nitrogen per acre per year is required, can be calculated. Using these assumptions, the total land area required for safe application of nitrogen would be 276 acres.

Although it will be shown that a significant amount of orchard land is available in the area, deposition of this material in apple orchards is not recommended. Organic nitrogen is not advised for use with productive apple orchards. For engineers not familiar with farming practice, it is advisable to contact local agricultural extension agents to obtain such details.

This method of arriving at an acceptable nitrogen loading rate is presented as a rational analysis based on the characteristics of the waste in question. It is meant to be conservative and adequate for Level I feasibility determination. Other methods, such as that based on crop uptake found in Module 3, "Soil as a Treatment Medium" can be used with liquid waste with a high proportion of inorganic nitrogen which will be readily taken up by plants. In this example, further analysis of the nitrogen content to determine what fraction of the TKN is ammoniacal would be helpful in Level II design.

Other methods of estimating nitrogen loads, such as relating loading to typical crop uptake rates, may be used.

Application of Water and Other Limitations - The quantity of water that infiltrates to the groundwater in the Olcott area probably exceeds 15 or 20 inches per year. The permeability of much of the area exceeds 2 inches per hour. Thus, it can be concluded that the transmission of water from the sludge will be a minimal problem. Using only 25 percent of the present permeability rates, the area of application would be less than 20 acres.

One important criterion that has not been discussed is the potential odor problem. Because of the high organic solids and grease content it can be assumed that the sediments will be anaerobic and have a strong unpleasant odor. For this reason, it would be suggested that the material either be placed underground by soil injection, or that it be covered with several inches of soil as soon as possible after application.

Area Requirements for Dredged Sediment Application

A summary of the application rates estimated to be acceptable and the resulting land requirements are shown in Table 4. It can be seen that the limiting factor is the nitrogen content of the sediments, pending any unusual problems in organic solids application. Nitrogen is often the limiting factor for application of sludges and wastewaters in cases where the application rate is controlled by the crop needs. If this is assumed to be the required land area, it can be seen that the application rates of the other pollutants are one-third to one-tenth that which is considered to be an environmentally safe rate of application. Recommendation of the use of a 300 acre site should incorporate a safety factor large enough to account for any unforeseen events. This application is equivalent to adding the dredged sludge once to a depth of 2.25 inches.

By comparing land area requirements due to various waste constituents, the limiting factor is determined. In this case it is nitrogen, although further study of organics loading is indicated.

Table 4. Summary of recommended application rates for various pollutants on 300 acres of agricultural land near Olcott, New York, and the related estimated safety factor above the detrimental level.

Pollutant or Substrate of Interest	Total Area Required (acres)	Safety Factor[1]
Toxic Elements	50	6
Grease and Oils	42	7
Organic Solids	35 (350)[2]	9
Nitrogen	276	1
Water	20	14

[1] Safety factor = recommended 300 acres/required area.

[2] Application to only 35 acres would cause increase in soil organics content, but would probably have little adverse effect on the soil system.

Site Evaluation Procedure

General Description and Land Use

It will be assumed that the distance which could be considered feasible for disposal, in view of the transportation costs, is limited to two miles from the sediment sites. A detailed review of the land area within a 2 mile radius from Olcott Harbor was conducted. The total estimated area included is 4320 acres. Thus, less than 10 percent of the total land area is required for safe application of these dredged materials.

The area around Olcott is quite flat with an average slope of approximately 1 percent (elevation ranges from 280 to 330 feet). There are some steeply sloped areas along the shoreline of Lake Ontario and tributary creeks.

Land use information is put in map form, indicating cropland, forest, orchard, and residential areas within an economical transport distance from the dredging area.

Orchards are an important agricultural activity in Niagara County and occupy a sizable portion of land in the Olcott area. The primary fruits are apples, tart cherries, and pears. In order to obtain a general overview of the various land uses, data from New York State's Land Use and Natural Resources (LUNR) inventory were utilized. The amount of land used in agriculture and other purposes is summarized in Table 5. These data were sketched to show the location of various land use practices in Figure 6. The total amount of the land area used in orchards and other agriculture is 53.5 percent. Figure 6 represents one of the required maps to be used during the site selection procedure.

In practice, the mapping procedures used in this example can be accomplished by using a USGS topographic map as a base map and making clear overlays for soil types, land use, and other factors to be considered in site selection. Preferred areas can then be identified readily by combining all overlays on the base map. This is represented in Figures 6 through 8.

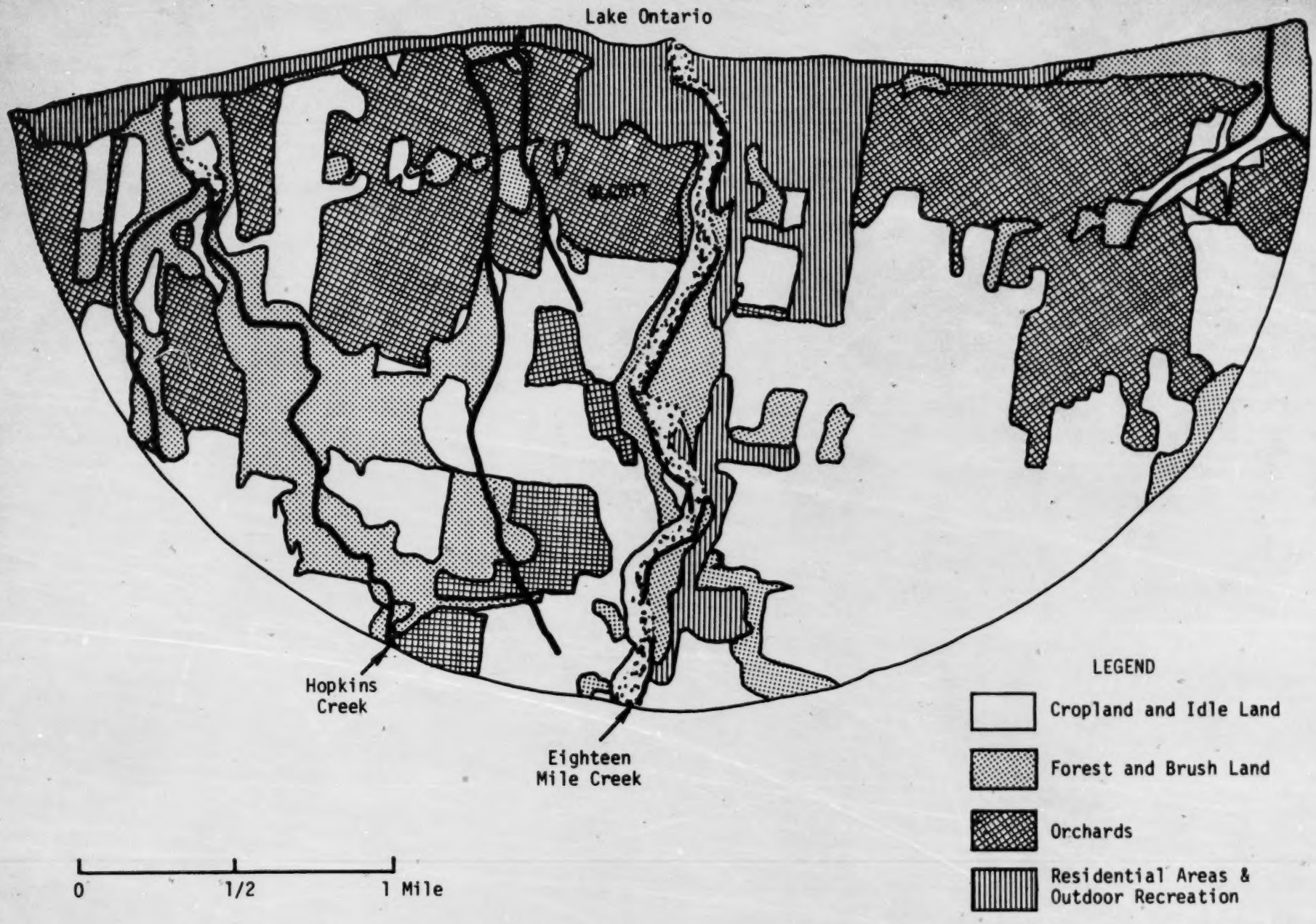

Figure 6. Land use practices and their distribution around Olcott, New York.

Table 5. Distribution of land use practices in Olcott, New York area.

Land Use	Hectares	Acres	% Area
Residential (Urban)	141	348	8.1
Cropland	320	791	18.3
Orchards	615	1520	35.1
Forest	292	722	16.7
Idle	337	823	19.3
Outdoor Recreation	45	111	2.5
Total	1750	4325	100.0

Soil Description

Examination of the soil survey map of Niagara County (Higgin, et al., 1972) indicates that three soil associations are included in the area within a 2 mile radius of the Olcott Harbor.

a. Howard-Arkport-Phelps association - Deep, somewhat excessively to moderately well drained soils having a medium texture to moderately coarse textured subsoil over gravel and sand.

b. Appleton-Hilton-Sun - Deep, moderately well drained to very poorly drained soils having a medium textured subsoil.

c. Minoa-Galen-Elnora association - deep, somewhat poorly drained and moderately well drained soils having a medium textured or moderately coarse texture, or coarse textured subsoil, over fine and very fine sand.

About 65 percent of the area belongs to the Howard-Arkport-Phelps association. This area borders Lake Ontario and is of high potential for agricultural production that is especially suited for growing fruits. More than 80 percent of the orchards in the area are located on the Howard-Arkport-Phelps soils.

The Appleton-Hilton-Sun association and Minoa-Galen-Elnora association occupy approximately 25 percent and 10 percent of the area within the two mile radius, respectively. Roughly 50 percent of the areas occupied

by crops or left idle are located on these two soil associations. In general, these three associations form bands paralleling the lake with the Minoa-Galen-Elnora furthest inland.

Many of these soils would appear to have characteristics which should enable deposition of polluted sediments with a minimum number of problems, as long as the rates of application are controlled. The pH is of concern if it is below 6.5. However, even though the surface soils may be below this level, the lower soil horizons are calcareous and would have a higher pH. The permeability of the soils presents a different problem than in most situations, since the good drainage and percolation rates of many of the soil types in this area might cause pollutants to be washed through to the groundwater before neutralizing reactions would have a chance to occur. In order to identify the best areas for disposal of the sediment, the following characteristics of the soil are desired:

Soils are grouped by their drainage and permeability, depth to groundwater, pH, and slopes and mapped for the same area used in land use mapping.

1. better drained, but slower permeability,
2. at least one foot depth to groundwater,
3. higher pH,
4. minimum slopes to control runoff.

Through consultation with a soil technologist, a soil grouping was suggested. The resulting soil type grouping is shown in Figure 7. The light area of this Figure is considered to have soils with characteristics which would be most acceptable for application of the lake sediment.

In order to more clearly relate the most desirable soil characteristics to the present land use, Figure 8 was developed by superimposing Figures 6 and 7 to illustrate the cropland and idle land that was associated with soils with the most desirable sediment disposal characteristics. This relationship indicates that there are approximately 900 acres available which combine agricultural land with the desirable soil characteristics.

Land use and soil characteristics maps are superimposed, yielding a map of available land with desirable characteristics for land application.

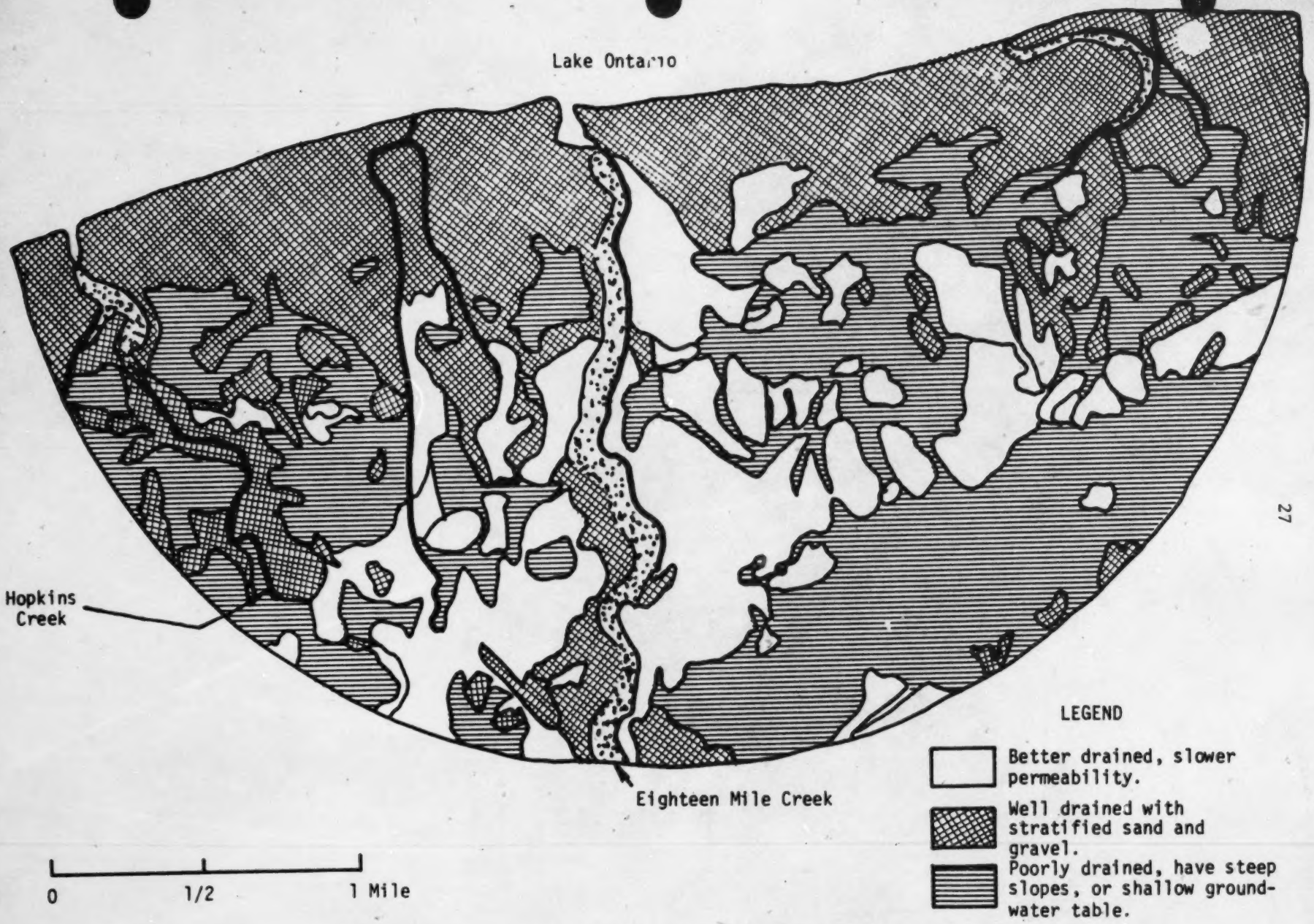

Figure 7. Distribution of soil types with characteristics of differing suitability for deposition of sediments.

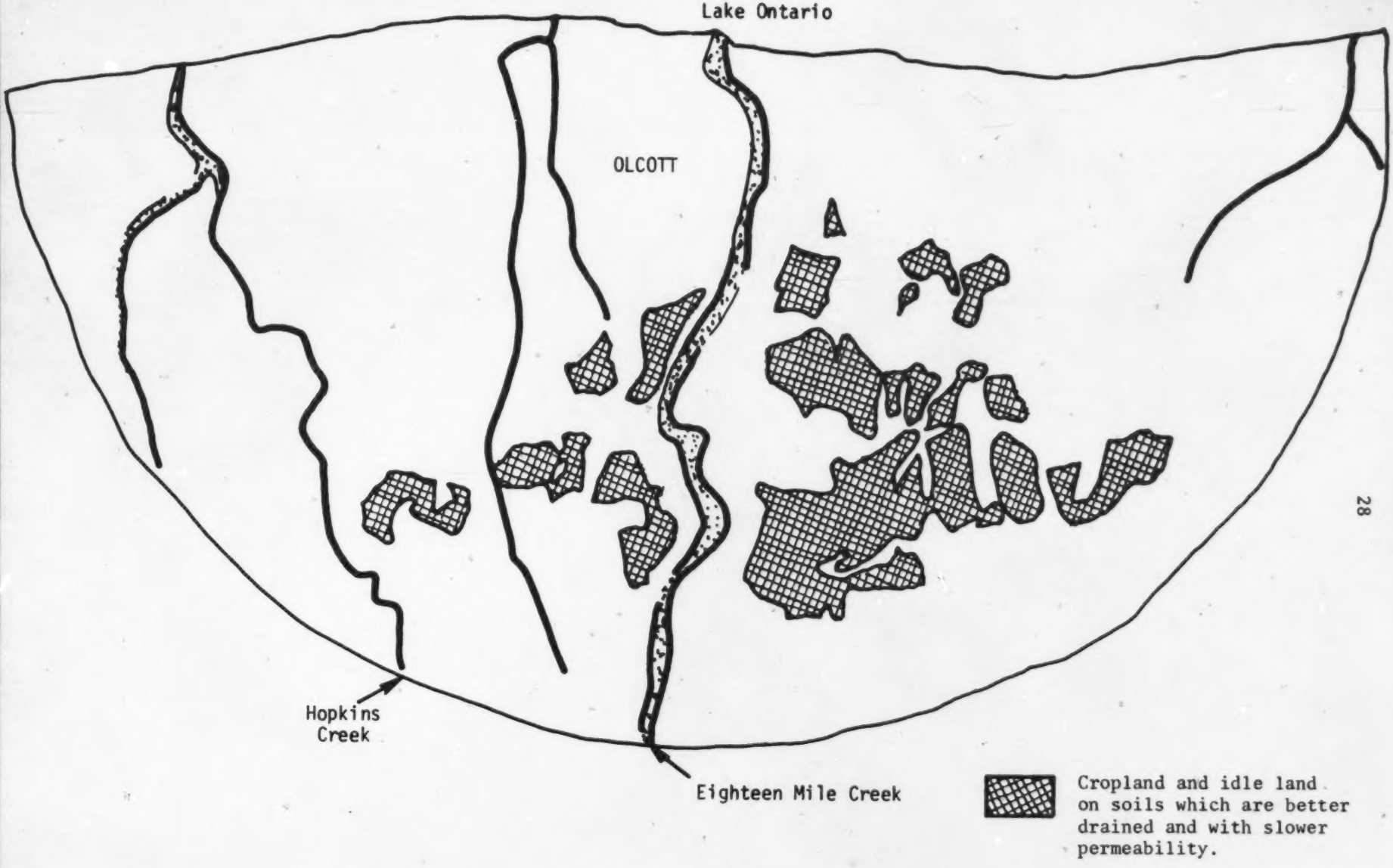

Figure 8. Identification of soil types suited to sediment disposal on agricultural land.

Discussion

Comparison of the recommended application rates and area requirements to the land area that has the most desirable characteristics indicated that sediment deposition on agricultural land would appear to be feasible, and limited by the nitrogen concentration. It would require about 35 percent of the available land meeting acceptable criteria for dredging disposal within a 2-mile radius of Olcott.

Further illustration of the relative impact of land disposal of the dredgings is illustrated in Table 6. The values are all approximations using estimated average characteristics. However, these values should serve as guides as to the potential impact of the addition of the dredged sediment to the soil. The mercury and zinc add significant amounts of material over that contained in typical soils (Page, 1974).

Table 6. Estimated increase of specific materials from the application of Olcott, New York Harbor dredgings to 300 acres of agricultural land.

Added Material	Increase in Top Soil, %[1]
VS	8
TKN	31
Zn	65
Hg	400

[1] Estimated increase over background quantities in top 2 feet of soil.

It had been anticipated that the toxic elements would determine the acceptable application rates. Although the addition of mercury is significant compared to typical background levels, the total additional concentration amounts to 0.47 lbs per acre. Two factors would indicate that this level may not be detrimental to the soil system. First, mercury levels commonly measured in some soils may be as high as 0.6 lbs/acre. Second, addition of this quantity of mercury with sewage sludge in Europe on agricultural cropland is practiced and considered to be acceptable. Although the zinc levels are also increased, common background levels in soil are also high in relation to the amount resulting from this addition.

Placement of the dredged sediment on land would not increase metal content to unacceptable levels, as may have been anticipated.

There is little doubt that the placement of Olcott sediment on agricultural land is technically acceptable and that the land area is available with suitable characteristics. Whether this practice is economically or politically feasible are two important areas that should be considered. Finally, the presence of chemical plants upstream from the harbor emphasizes the need to be conservative when dealing with these dredgings. It might be useful to test the recommended application rates in short plant growth tests to determine any potential unexpected impact.

Level II analyses are not discussed in this module, including crops, legal aspects, climatic factors, detailed costing, application systems, monitoring and drainage requirements. Also, in a complete design, toxicity potentials, organics, nitrogen, and phosphorus considerations would be explored in much greater depth. In particular, the limiting nitrogen application rate would be evaluated with respect to all possible uptake mechanisms so that the rough calculation of N loading and land requirement presented in Level I can be refined. This will determine application area for detailed system

Level II design includes detailed analysis of factors discussed in Level I, plus other design considerations. Nitrogen and organic loading estimates would be refined.

design. The Level II Module 15, "Nitrogen Considerations" must be consulted to perform this analysis. Also, in the case of this waste, some uncertainty exists in the estimation of safe organic loading. Further study of this question is warranted, although nitrogen should remain the limiting design factor. For this example, pathogens and wastewater storage would receive little or no attention. In more typical wastewater and sewage sludge application problems, they would.

Public acceptance must be considered in land treatment planning. This can be enhanced by working with members of the community who would be affected by the project.

One important consideration included in the Level I analysis is also not discussed in this module. Societal factors, or public acceptance, can have a great bearing on land availability and the ability of the designers to carry the project to completion. This factor, in practice, is intimately related to local and national laws and regulations. Land application proposals must be justified within the framework of these requirements.

Finally, as with any other engineering design procedure, comparison must be made with alternative treatments. This must be done in terms of economics and treatment potential in order to determine feasibility and decide which option to implement. This analysis is to be initiated in the Level I design procedure, and at this point a decision is made as to basic feasibility and cost-competitiveness of land treatment versus conventional alternatives. This decision is whether to proceed to the Level II detailed feasibility design for land treatment. Only those alternatives which are obviously not competitive are discarded at the completion of Level I, and further economic comparison is made with conventional options following Level II, at which point a system is recommended and final design will commence on the chosen system.

Economic comparison must be made with conventional treatment alternatives, for Level I and II feasibility analyses.

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E. L. Stone, Agronomy	Principal Faculty Advisor

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J. E. Stone, Agronomy

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DESIGN PROCEDURES FOR LAND APPLICATION OF WASTES

Objectives

Upon completion of this module, the participant should be able to:

1. Indicate the purpose of a Level I or preliminary design.
2. List five steps in a Level I design.
3. Indicate the entry point into Level II or detailed design.
4. List the processes that are in a general engineering design procedure that are not in a Level I or II design.
5. Indicate which modules are Level I modules.
6. Indicate a "limiting factor" given the land areas necessary to safely apply the different constituents in a wastewater sample.
7. Calculate the "safety factors" in land treatment for all constituents but the limiting constituent.
8. Indicate what is meant by a Level I site selection.

RETURN TO LESSON PACKAGE

Script to Accompany the A-T

DESIGN PROCEDURES FOR LAND APPLICATION OF WASTES

Module 6

January, 1978

DESIGN PROCEDURES FOR LAND APPLICATION OF WASTES

(Slide 1) This module provides a framework for utilization of the information presented in all the other modules of the program. The goal of this module is to develop a general procedure based on an understanding of the pollutant management capabilities of soils, for evaluating the feasibility of land application of waste under various conditions. The objectives can be located in the envelope that came with this lesson. Find the objectives, turn off the recorder and study them (slide 2). You may keep the objectives for reference during this lesson.

The rational problem-solving approach common to much engineering practice can be diagrammed as in slide 3. The diagram and the approach includes six separate steps from problem definition through evaluation of the implemented solution. Step A, defining the problem and listing possible solution considerations, and Step B, deciding on the initial feasibility of the suggested solutions and retaining the viable solutions for further consideration are activities that we call Level 1 design in this program (slide 4). All the information necessary to complete these steps are in the Level 1 modules, which are the seven preliminary modules.

The next step is to identify, in depth, the major limitations of the design and to identify any factors which might prohibit implementation of viable solutions. The detailed solution is then defined. This is considered a Level II design, and is completed using all of the modules (slide 5). Any pilot plant analyses or field investigations would occur at this stage. The solution is then implemented. Under ideal conditions the implemented solution would be evaluated and its effectiveness in solving the original problem examined. This would lead to feedback which would be valuable in improving engineering practice. Unfortunately, this last step is often not able to be included in planning and design so that this type of feedback is usually minimal. Documented experience from other projects usually substitutes for this step. Thus this program is designed to take the participant through step C in the solution to a waste treatment problem.

Slide 6 indicates the three important pieces of information which participants should be able to develop upon completion of this design procedure.

It is the goal of this program to enable the participants to be able to make feasibility decisions with several hours of study after the problem has been defined, and to provide estimates of types of systems, potential site locations and cost-effectiveness of land application of wastes after additional investigation (slide 7).

Seldom have those involved with the development of waste management systems had to deal with as many variables as in the design of land application of wastes (slide 8). These systems require integration of physical, chemical and biological pollutant control phenomena with climate, crop production, and uncontrollable nature phenomena. In order to complete Level I design, participants should be familiar with the information presented in the first six modules indicated in slide 9 and in the inside cover of all the printed modules. Only the most prominent considerations are included at this level, and detailed descriptions are kept to a minimum.

There are two general temptations for the program participants at this point. Some may become frustrated with the lack of detailed definitions and descriptions (slide 10). The information in the first six modules, however, should be viewed as being analogous to seeing only the "tip of the iceberg", and is used for obtaining a general overview. A considerable amount of supporting material is provided in subsequent modules.

The second temptation is that the initial information will be adopted as inflexible "rules of thumb". It should be kept in mind that the objective of the Level I design is to obtain data rapidly for initial feasibility decisions. The decisions and limitations defined at this point should be considered temporary until further supporting data is developed.

There is an envelope labelled "Design Procedures" in the box that contained the lesson (slide 11). Find that envelope and take one set of stapled pages. This set of pages will be very helpful in solving any design problem and you may keep them for future reference (slide 12). Slide 13 indicates the general preliminary or Level I design procedure. There is a copy of this slide with the stapled papers. The waste problem is defined by a characterization study which sets the stage for estimating the land area necessary. Level I module, "Waste Characteristics", is the key

source for defining the waste parameters. If one or more of the waste parameters are far outside normal limits, modification of the effluent at the source may be required. This is usually done for an industrial source and might be through preliminary treatment or through inplant modifications.

The estimate of the required land area is based upon an application rate for each potential pollutant that satisfactorily controls that particular pollutant. Slide 14 illustrates an example of the results of this type of analysis. Usually, one waste parameter, nitrogen in this example, determines the largest land area required for safe application of the wastes. This is then identified as the limiting factor in the Level I solution. For all of the other parameters the waste could be applied at a higher rate, or to a smaller area. Comparison of the land area required for safe application of each of the other pollutants (slide 15) to that required for the limiting factor is indicative of the safety margin involved in the application of that waste parameter. It should be kept in mind that the initial limiting factor analysis procedure is to obtain data rapidly for initial decisions. The limiting factor analysis must be revised in the detailed, Level II design procedure. The site evaluation should, at this point, only indicate the availability of a suitable site or sites with the required soil properties within a suitable radius. Approximate costs are developed and finally land treatment is compared to other alternatives. This comparison could find land treatment not feasible for one or more legal, technical or social reasons, less cost effective by far than conventional treatment which would make the conventional treatment more attractive, or more cost effective or even close to the same cost effectiveness. These latter conclusions would lead the designer to proceed to the Level II analyses.

The various topics that are considered for a Level I design are indicated in slide 16. Slide 17 indicates the Level I modules that relate to each of these topics. The information in this slide is very important as a guide to the Level I modules and is included in the stapled pages that were obtained earlier. The lines that are thicker indicate the main

sources of information for that particular topic. The main source of information concerning problem evaluation, for example, can be found in the module on waste characteristics. There is also, however, important information on that topic in the module, "Societal and Legal Constraints". After the decision is made to pursue land application further, Level II analyses begin. This level is characterized by a greater depth of analysis of pollutant-soil interactions, and considerably more attention to potential site location and evaluation. Slide 18 is a summary of the general procedure that has been found to be effective for developing a Level II, or detailed, design. The first step in this procedure is a detailed examination of the information concerning the individual potential pollutants. This can cause a revision of the initial land area estimates for safe application and also change the safety factors. Detailed site evaluation and the type of land application system suitable for the particular sites and waste characteristics are then carried out. After an economic analysis the land treatment system decided upon is compared to other alternatives leading to a final decision.

The Level II analysis in this problem ends at Step C in slide 19. Actually, this detailed analysis is essentially a repeat of the preliminary design procedure, with greater emphasis on the specific waste characteristics, type of land application system, and specific site evaluation.

The rest of this module describes an example of the Level I design procedure. Since Level II is essentially the same as Level I except, in great detail, it is not incorporated into the example.

This example investigates the possibility of applying harbor dredgings to the soils around Olcott, New York (slide 20). It would be more typical to investigate the possibility of applying municipal or industrial wastewater or sludge to the soil, but this example will emphasize the general applicability of this design procedure. No costing feasibility of applying the dredgings to the soil will be developed in this example, therefore, it will not be compared to the alternative disposal methods indicated in slide 21. Generally, however, there are great drawbacks to dumping and lagooning. The former because of environmental legislation, the latter

because of cost and environmental legislation. The problem, evaluation of which is the first step in the preliminary or Level I design procedure, is indicated in slide 22. The second step, according to the printed sheet specifying Level I design procedure is to quantify the pollutants of interest to land application. The Level I module, "Waste Characteristics", indicates the characteristics that are of concern. Slide 23 indicates those characteristics and the amounts in the dredgings. Notice that the quantity is 30,000 cubic meters of sediment. Notice also, that the composition of the sediments was obtained from an average of six samples. These samples were obtained from different sites in the harbor and the assumption is that the sediment is uniform in composition throughout the harbor. This assumption may be spurious. The next step is to estimate the necessary land area to safely apply the different constituents in the sediment. The main source for information of a preliminary nature is found in the "Soil as a Treatment Medium" module. Heavy metals and other potentially toxic elements are of concern whenever sediment, or sludge is applied to the land. Slide 24 is a table that indicates the recommended maximum sludge metal additions to farmlands. This table is also found in Module 3, "Soil as a Treatment Medium", and is developed from USDA guidelines and EPA recommendations. Assuming the soil to have a CEC of 5-15 milliequivalents/100g, the land area necessary to apply the potentially toxic elements can be computed. An example of this computation for zinc is shown in slide 25. This computation would be carried out for all of the potentially toxic elements in the sediment. The computation of lead indicates a land area less than that for zinc. Between these two potentially toxic elements, therefore, zinc, is the limiting pollutant as far as safe land application is concerned.

Because oils and grease (slide 26) in this relative quantity, are such a specialized problem, it is necessary to turn to the research literature. Since large quantities of petroleum products are lost to the environment every year, there is considerable information on the effects and fate of greases in soil (slide 27). In general, since most oils and greases are decomposed by microbial activity, the environment is capable of accepting large quantities of these products. The suggestion

we will use is that one kilogram of oil per square centimeter is the maximum safe application rate. Using this rate, our sample sediment would require 170,000 square meters or 42 acres (slide 28).

Using this same procedure for the other components in the waste, we end up with a minimum land area for each constituent in the sediment. This is indicated in slide 29. The land area computation is, however, not a "cook-book" computation. Figuring the land area for safe application requires that the designer know, among other factors, the type of soil in the area, the crops that will be grown and the climate in the area. It can be seen from this table that nitrogen is the limiting factor in the Olcott sediments. Using 300 acres for a site size should incorporate a safety factor large enough to account for any unseen events in the case of nitrogen and, would provide for an application rate that is one half to more than one tenth the environmentally safe rate for the other potential pollutants in the sediment. This is indicated by the safety factors in slide 30.

The next step in the Level I design procedure is a preliminary site evaluation. At this stage, the site evaluation is to indicate the availability of a site or sites within a reasonable distance.

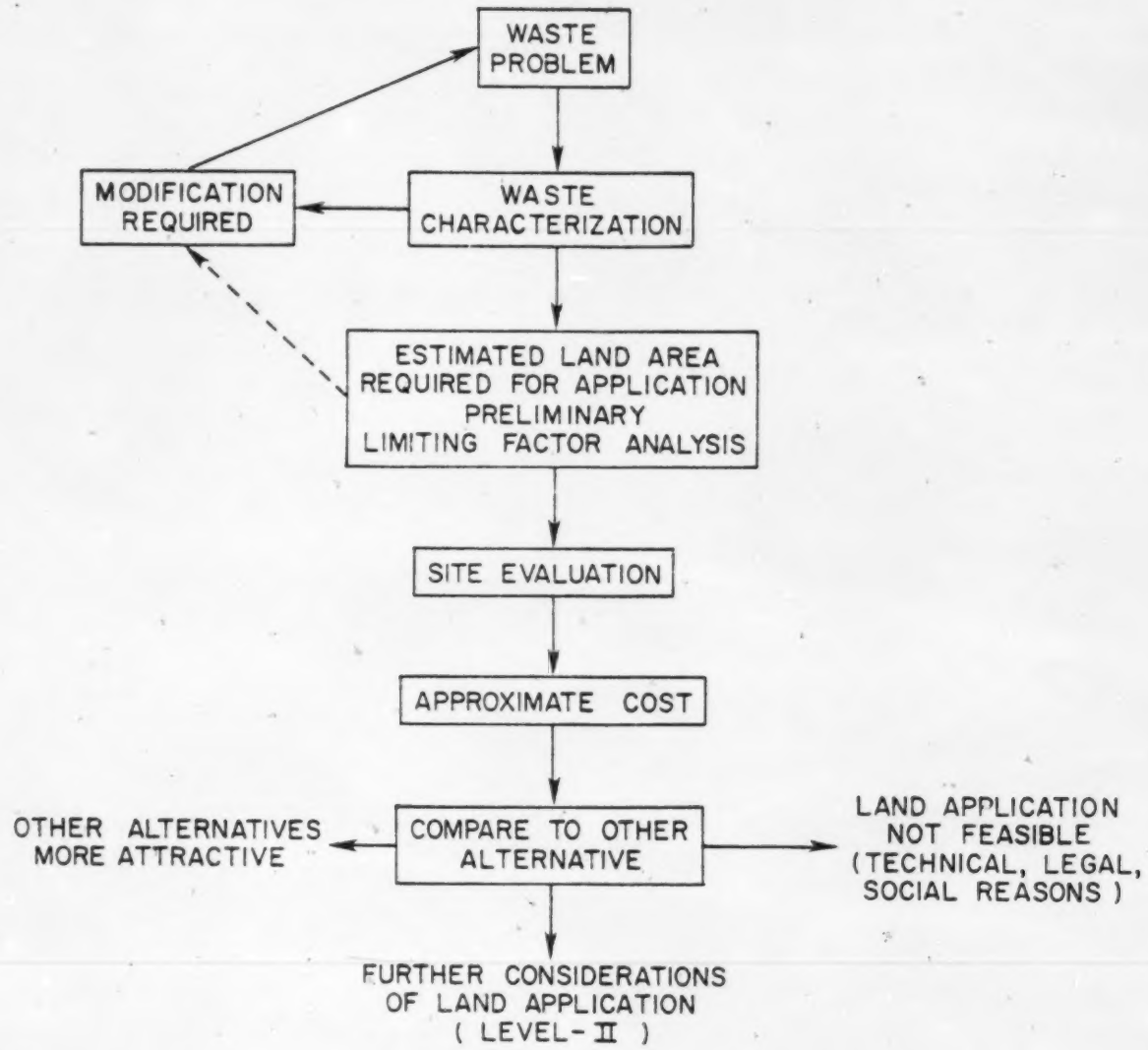
It will be assumed that the distance which could be considered feasible for disposal, in view of the transportation costs, is limited to one and a half miles from the sediment sites. A detailed review of the land area with a 2 mile radius from Olcott Harbor was conducted (slide 31). The total estimated area in this radius is 4320 acres. Thus, less than 10 percent of the total land area is required for safe application of these dredged materials. Slide 32 indicates the distribution of land use practices in the Olcott area. Notice that orchard land is the primary agricultural use for the land. Agriculture is the main use of about 55% of the land in the area under consideration. Slide 33 indicates the location of the various types of land use. This land use map is one of the maps that is generally required when designing a land treatment site.

There are three soil associations located in the area of interest. About 65% of the land is well drained with high permeability. This land is mainly used for orchards. The other two associations range from moderately well drained to poorly drained. The permeability ranges from slow to very

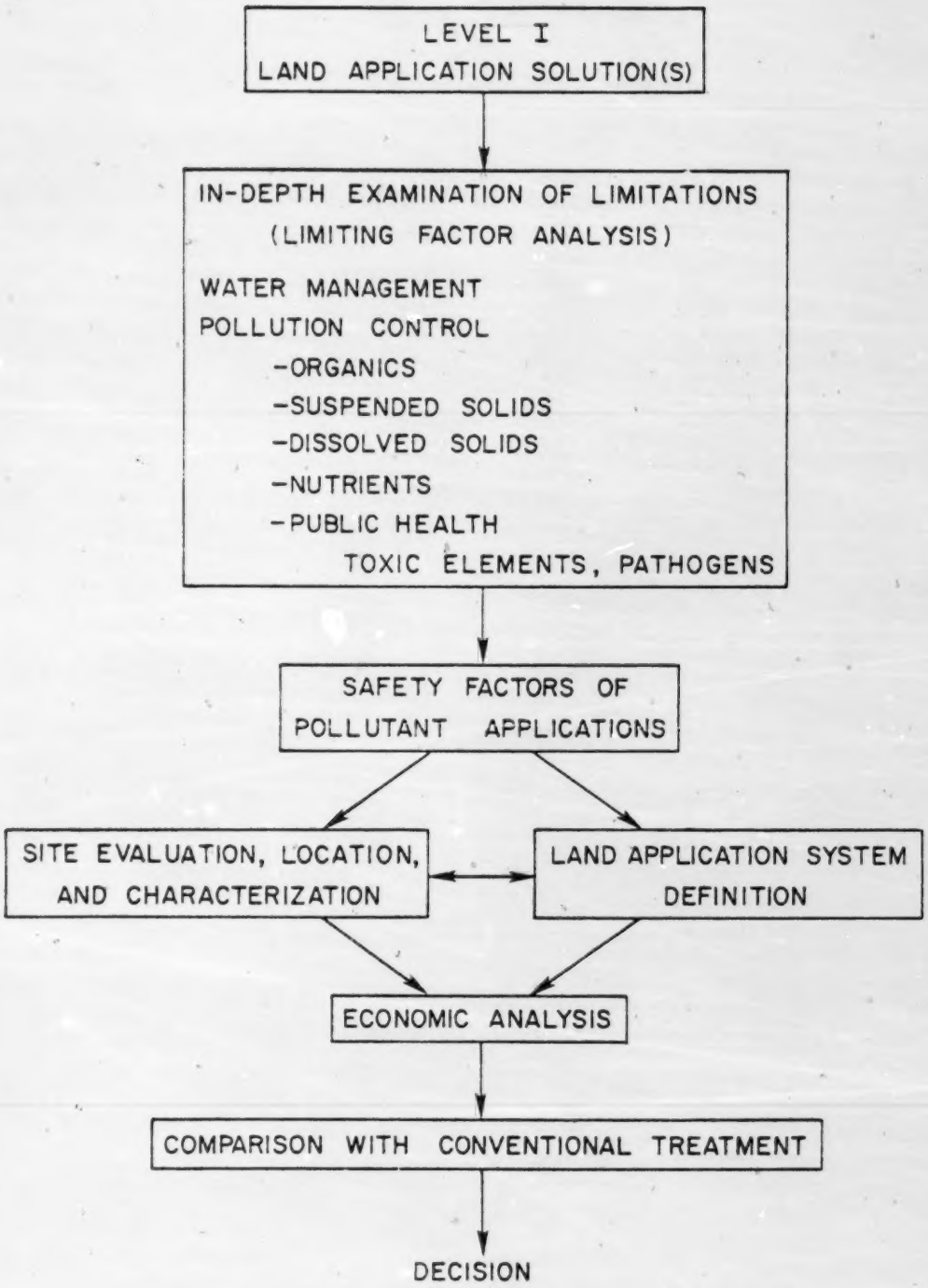
slow. Slide 34 indicates the type of soil for which we are looking in this example. The slow permeability is to protect the groundwater from leaching of pollutants, before neutralizing reactions have a chance to occur. A soil map that indicates the location of the different types of soil and with the different characteristics was developed for the area of concern. This is shown in slide 35. Superimposing the maps in slide 33 and 35 results in finding the proper set of land use and soil characteristics that would suit the purpose for this design. The potential sites are indicated in slide 36. It can be seen that there is enough land area in the Olcott area to satisfy the design parameter of 300 acres for safe application.

The rest of the Level I design procedure would consider the cost and compare land treatment to alternative methods of disposing of the sediment. There would also be an examination of the social aspects of taking up about 30% of the available farmland in the immediate Olcott area for a one-time land treatment scheme. If the situation seems to indicate further investigation of land treatment the designer would enter the detailed design procedure -- that is Level II (slide 37).

This module has described a procedure for using the Land Application of Wastes modules (slide 38). With these modules the professional can design a land treatment site or evaluate a design and compare it to conventional treatment. The printed material that accompanied this module will act as a guide in this procedure.


WASTE PROBLEM
MODIFICATION REQUIRED
WASTE CHARACTERIZATION
ESTIMATED LAND AREA REQUIRED FOR APPLICATION PRELIMINARY LIMITING FACTOR ANALYSIS
SITE EVALUATION
APPROXIMATE COST
OTHER ALTERNATIVES MORE ATTRACTIVE
COMPARE TO OTHER ALTERNATIVE
LAND APPLICATION NOT FEASIBLE (TECHNICAL, LEGAL, SOCIAL REASONS)
FURTHER CONSIDERATIONS OF LAND APPLICATION (LEVEL-II)

SIMPLIFIED LEVEL-I DESIGN PROCEDURE FOR LAND APPLICATION OF WASTES



LEVEL II DESIGN PROCEDURE FOR LAND APPLICATION OF WASTES

LEVEL-I FEASIBILITY OF LAND APPLICATION OF WASTES
(TOPIC INTERACTIONS)